Development of a Synchronous High-Speed Acoustic Communication and Navigation System for Unmanned Underwater Vehicles

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LONG-TERM GOALS

Our long-term objective is a smart acoustic network for multiple underwater vehicles operation, with integrated communication and positioning capability. The final objective of this one-year proposal is to provide navigation and communications (acoustic and radio waves) to one Undersea Search and Survey (USS) underwater vehicles using a set of three dedicated synchronous buoys and a high-speed acoustic link (HPAL or Mills-Cross) to upload sonar images. Also, wireless communication to shore will be available for control and real-time data transfer. The underwater vehicles will be carrying the latest version of the compact low-cost Dual Purpose Acoustic Modem (DPAM).

OBJECTIVES

To provide navigation and communications (acoustic and radio waves) to one UVV using a set of 3 dedicated synchronous buoys and the FAU Mills-Cross to upload sonar images. Wireless communication to shore must be available for control and real-time data transfer.

APPROACH

The acoustic communication/navigation network is designed to fulfill the following functions (see Figure 1):

1) Synchronous navigation: navigation operations are significantly more power efficient and accurate if the network is synchronous, thanks to a faster ping rate. Synchronous navigation is achieved through accurate internal clock drifts by only thirty microsecond per hour between GPS fixes. The whole concept is to make the most efficient use of time and frequency band available.

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14. ABSTRACT
Our long-term objective is a smart acoustic network for multiple underwater vehicles operation, with integrated communication and positioning capability. The final objective of this one-year proposal is to provide navigation and communications (acoustic and radio waves) to one Undersea Search and Survey (USS) underwater vehicles using a set of three dedicated synchronous buoys and a high-speed acoustic link (HPAL or Mills-Cross) to upload sonar images. Also, wireless communication to shore will be available for control and real-time data transfer. The underwater vehicles will be carrying the latest version of the compact low-cost Dual Purpose Acoustic Modem (DPAM).

15. SUBJECT TERMS

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2) Communication between buoy, HPAL and the USS-underwater vehicles in FH-MFSK mode for maximum reliability [1-2].
3) USS vehicles to HPAL communications: each message can be MPSK-encoded for high data rate [3-7].
4) Data to and from shore (or boat): while the USS-underwater vehicles are listening to the buoys, all the data collected can be transmitted to shore (or a boat) using the deployable RF antenna.

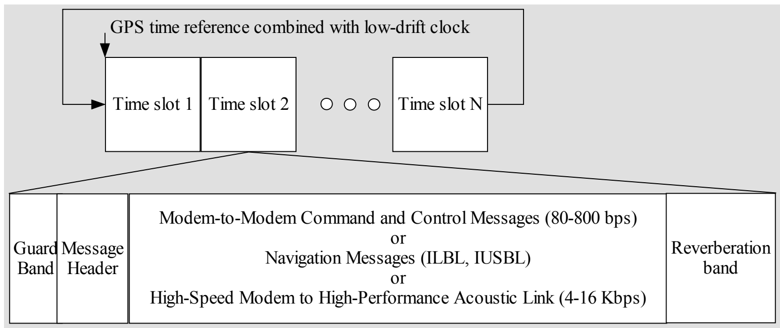

Figure 1. Time-Division Format for the Synchronous Communication/Navigation Network.

WORK COMPLETED

1) Acoustic Modem Software

The DPAM software runs on FAU's DSP hardware module, which contains two computing devices: a low power Motorola micro-controller (M68VZ328) and a high performance TI DSP (TMS320VC5416). The micro-controller runs the Host code as a task under the ucLinux operating system, and the TI DSP runs the DSP code. The Host code implements the DSP module external communications interfaces, such as Ethernet and serial ports, a real-time clock, and some general DSP module board control functionality. The DSP code implements the actual acoustic modem and navigation software, including the DAC/ADC interface.

a) Software Improvements

- Significant effort was taken to apply a uniform software coding standard to the various bits and pieces of the Host and DSP code. The FAU DPAM software is now very close to industry standards.
- The FAU DPAM serial interface has been significantly improved, so that the modem be easily installed and controlled by autonomous vehicles.

b) New Software Capabilities

- Data Recording: The DPAM Host code has been upgraded, and a specific DSP code module was created to perform data recording. The DSP module can now record up to 55 seconds of raw data samples.
- Navigation Software: A variety of modifications were made to the original Host and DSP modem code to accommodate the integration of Navigation code into the existing design. These include the introduction of time multiplexed transmit slots to schedule the transmissions from various modems to prevent collision. See section c) below for more details.

c) Transmit Time slots

All transmissions from a specific modem are now confined to occur only in specific transmit time slots which are derived from the user assigned modem ID numbers for communications (comid) and navigation (navid). The total number of transmit time slots and the transmit time slot duration are also configured by the user. In the special case where the user configures comid = navid, communications

and navigational transmissions from that modem share the same transmit time slot. Navigational transmission are allowed on every allocated transmit time slot, but communications transmissions are only allowed if the previous transmission was a navigational transmissions. This scheme can alternate navigational and communications transmissions queued simultaneously, and allows for continuous navigational transmissions when no communications transmissions are queued.

2) Equipment

This section describes the equipment developed (in part) and used within the scope for this project. Figure 2(a) shows the FAU HPAL. Figure 2(b) shows the modem in topside configuration. Figure 3 shows the system diagram of the communication packaged within each buoy. Figure 4(a) shows the navigation/communication buoys in packaged form, while Figure 4(b) shows the electronics package.

Figure 2. (a) FAU HPAL (Mills-Cross Receiver) before Deployment and (b) DPAM Topside Configuration.

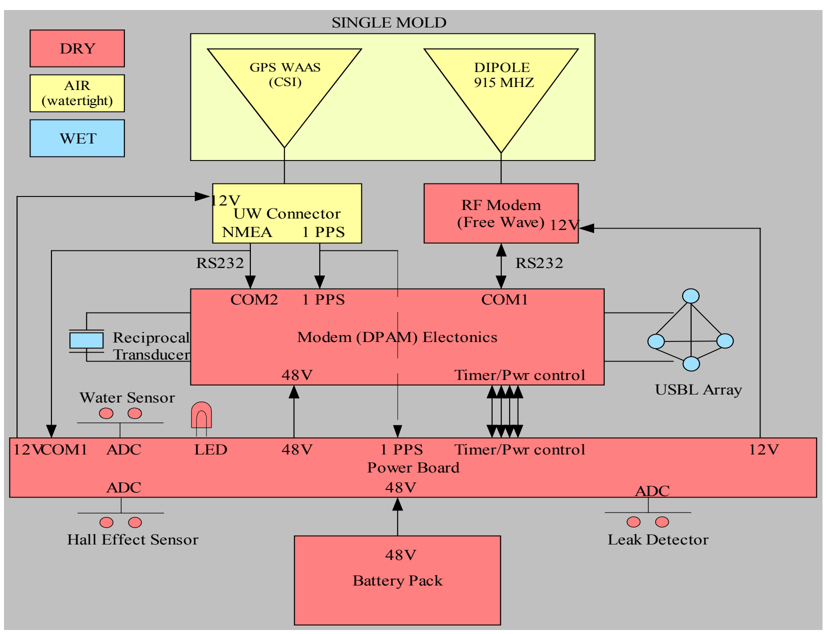

Figure 3. Communication/Navigation System Diagram.

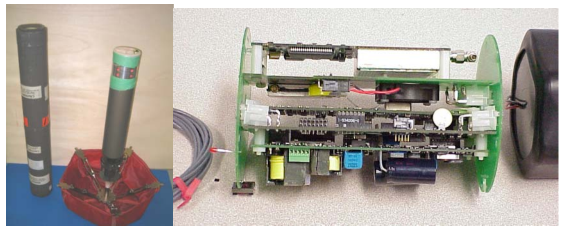

Figure 4. (a) FAU Telemetry Buoys and (b) Contained Electronic Package.

RESULTS

1) <u>DPAM to DPAM Communication Test (26/03/03, 04/04/03, 07/05/03)</u>

This experiment consisted in testing the performance of the DPAM. It required two boats, each one carrying a DPAM for transmission – reception. The modems are set up at distances of 1, 2 and 3km. At each location each modem sent every of the modulation and encoding schemes, which corresponded to a total of 12 different type of messages sent by each modem. Each modem processed the incoming messages using the 4 hydrophones available, taking advantage of spatial diversity [1-2]. 12 combinations of modulation and Forward Error Coding (FEC) were used to transmit the same binary content. For each combination, 10 messages were transmitted in each direction for the purpose of averaging. Figure 5 shows the experiment locations. Table 1 shows the percentage of received messages as a function of the transmission mode, FEC and range.

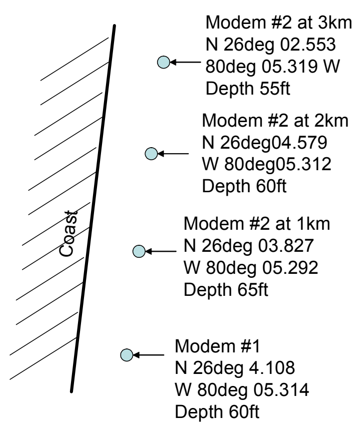

Figure 5. Locations of the 2 acoustics modems.

Table 1. Modem-to-modem results.

Mode	FEC	% of received		
		1km	2km	3km
4	Concatenated	100	80	100
4	Viterbi	100	60	50
4	Reed Solomon	100	100	60
3	Concatenated	100	80	50
3	Viterbi	100	90	90
3	Reed Solomon	90	80	50
2	Concatenated	40	20	0
2	Viterbi	40	0	0
2	Reed Solomon	0	0	0
1	Concatenated	50	0	0
1	Viterbi	60	0	0
1	Reed Solomon	20	0	0

2) <u>DPAM to Mills-Cross Data Acquisition (07/14/03, 08/15/03, 08/23/03)</u>
The DPAM was configured in FH-MFSK modulation mode. The HPAL was set up underwater at location 26 04.176N, 080 05.358W. The modem was placed 500 m west of the HPAL, then 500 m south and finally 1km south of the cross. 12 combinations of modulation and Forward Error Coding (FEC) were used to transmit the same binary content. For each combination, 3 messages were transmitted from each location for the purpose of averaging. Only 4 channels of the HPAL were used to match the receiver characteristics of the DPAM. Figure 6 provides an overview of the experiment locations. Table 2 shows the percentage of received messages as a function of the transmission mode, FEC and source location.

Table 2. Message correctly decoded by the Mills-Cross using 4 channels.

Mode	FEC	% of received messages		
		South	West	1km
4	Concatenated	100	100	100
4	Viterbi	100	100	100
4	Reed Solomon	100	100	100
3	Concatenated	100	100	100
3	Viterbi	100	100	100
3	Reed Solomon	100	100	100
2	Concatenated	100	100	100
2	Viterbi	100	100	100
2	Reed Solomon	100	100	100
1	Concatenated	100	100	100
1	Viterbi	100	100	100
1	Reed Solomon	100	100	100

3) <u>DPAM on UUV to Mills-Cross Data Acquisition</u>
The objective of this mission was to transmit canned side-scan image snippets (6 kbytes each) from a UUV to the HPAL (Figure 6). The collected data have not been processed at the time of this report.

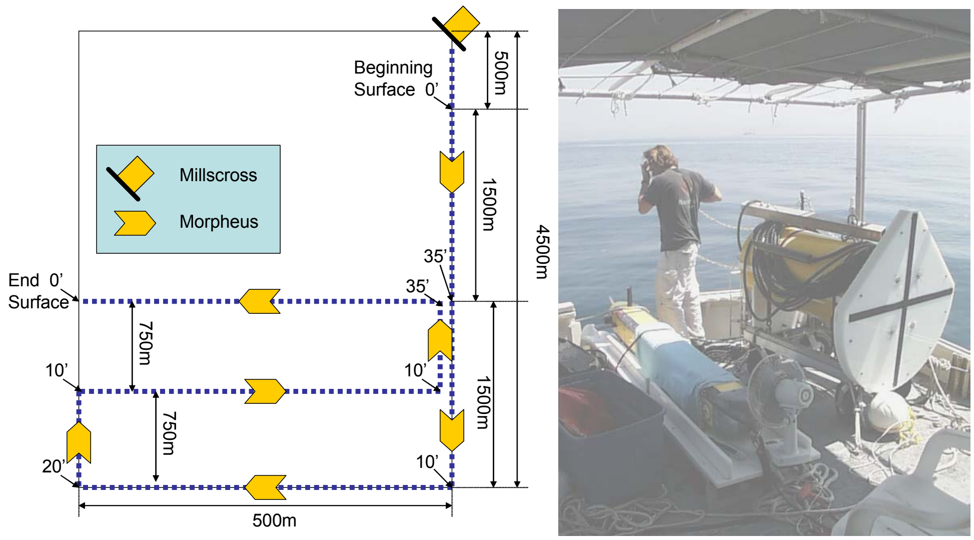

Figure 6. High-Speed Data Transmission from a Morpheus UUV to the HPAL.

IMPACT/APPLICATIONS

A new type of synchronous underwater acoustic network has been developed at Florida Atlantic University, designed to provide communication and navigation features between underwater platform, and relay the information to users using RF technology. This project intends to demonstrate the feasibility of synchronous TDMA networks for underwater applications.

TRANSITIONS

The technology developed for the DPAM has been disclosed. FAU and EdgeTech Inc. are currently working on transitioning this technology to the industry.

RELATED PROJECTS

“Smart Acoustic Network Using Combined Fsk-Psk, Adaptive Beamforming and Equalization”, Dr. P-P. Beaujean (PI) and Dr. Steven G. Schock (Co-PI). Sponsored by the Office of Naval Research (Dr. T. Swean). ONR award no. N00014-96-1-5031.

“FY02 South Florida Ocean Measurement Center Proposal, Acoustic Gateway”, Dr. P-P. Beaujean (PI), Dr. E. An (Co-PI) and Dr. A. Folleco. Sponsored by the Office of Naval Research (Dr. T. Swean). ONR award no. N00014-98-1-0861.

“Development of an Air Deployable Self-Mooring A-sized Navigation and Communication Buoy for Support of Littoral AUV Missions”, Dr. F. Driscoll (PI) and Dr. P-P. Beaujean (Co-PI). Sponsored by the Office of Naval Research (Dr. T. Swean). ONR award no. N00014-02-C-0407.

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Pierre-Philippe Beaujean, Lester LeBlanc, “Spatio-Temporal Processing Of Coherent Acoustic Communication Data In Shallow Water”, IEEE Oceans’2000, Sept. 2000, Providence, RI.

PUBLICATIONS

Pierre-Philippe J. Beaujean, E.P. Bernault, “A New Multi-Channel Spatial Diversity Technique for Long Range Acoustic Communications in Shallow Water”, Proc. of MTS/IEEE Oceans’2003, September 2003, San Diego, CA. [published]